A Report
On

Lightening And Lightening Protection of Overhead Transmission Line

Summer Fellowship Program-2014

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Under the Guidance of

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Certificate of Project Completion

This is to certify that Mr.**RAHUL NARENDRA NANDESHWAR** has successfully completed the project work titled ”LIGHTNING AND LIGHTNING PROTECTION OF OVERHEAD TRANSMISSION LINE in partial fulfillment of requirement for the Summer Fellowship Program-2014 at Electrical Engineering Department Under Guidance of Prof. Uday Kumar prscribed by Indian Institute of Science, Bangalore-560012.

This project is the record of authentic work carried out during the 16 June to 15 Jully of year 2014.

Prof. Udaya Kumar

Abstract

Over the last few decades, the electric utilities have seen a very significant increase in the application of not only for industrial but also for domestic and commercial purpose. With the significant in power generation to meet growing demand, the transmission system has to be augmented to transfer the bulk power generated to the load centre. The general transmission lines gets very much affected by lightening thunder (leader stroke) while working steadily at its normal working period.

Lightening effects on transmission line have always been a matter of concern in studies of power distribution, transmission and up gradation of transmission system. The magnitude and shape of the lightening on transmission line will be in undetermined and unpredictable form. It takes place for some microseconds to milliseconds and as it arises (immerges on object), it causes an serious damage to the system where it immerges.

The analysis of lightening leader (strokes) arising in distribution and transmisssion system is assuming increased importance. This is mainly because such studies yield neccessary information about the possible damage on different component which will determine their proper design as well as their persistance protection strategies .Height dependent model is universally accepted production Industry standard for both distribution and transmission. In this report general studies carried out to obtain analysis of 220kV/400kV and 765kV transmission line structure models compared them with existing configuration of 220kV/400kV and 765k transmission line.

Several parts of an overhead transmission line have to be included in a model adequate for lightning studies. Along with the study about the transmission lines study and their structure analysis. Some calculation has given which explains the protectiveness of given structure . The main purpose of this report is about studying the structure of generalised transmission lines which are existing for comertial Benefits. i.e transmission of huge ammount of energy from source to destination. ”Including the protective study of HV (more than 100kV) and EHV(345 to 765kV) lines. ”

Contents

List of Figures

Chapter 1

Introduction to Lightening and Lightening Protection

1.1 Introduction

From the earliest days of the power industries , lightening faults on lines as well as equipment fault have been the major cause if intertrruption of to service. With the growing importance of electric power to both industrial and residential costemers, attention was increasingly directed towards protective system and devices to improve service continuity . At an early stage, the source of overvoltage was believed to be induction from the electric charge of the thundercloud, and this led to installation of grounded conductors usually erected above the power conductors to divert some of the induced charge from them.

As the importance of service continuity increased, differing philophies of protection developed , along with improved defination of the indices of service reliability .[1] It is now generally agreed that both the frequency and duration of service interruptions are such indices, with their relative importance varying with the size and nature of the load. Improvement methods may be cvlassified as those intended to prevent the occurance of the system faults and those intended to mitigate the effect of the fault on the sound portion of the system. Accordingly, mordern philophies of transmission lines protection may be grouped as follows:[1]

- Prevention of flashover of the line insulation;
- Acceptance of insulation flashover, clearing the fault as rapidly as possible, and reclosing the circuit after a short intentional delay to permit the deionization of the arc path

- Provision of multiple supply paths to permit the temporary loss of any one without loss of service to any load a special case of multiple supply paths is the double circuit line; the reliability of such lines is not equivalent to that of two well- shaped single- circuit lines because of the possibility of a double circuit outage from a single lightening stroke.

As considered here , transmission lines are defined as lines operating at phase-to phase voltages in excess of 100 kV. For conveinient reference, the following classifications will be used :

high-voltage (HV) lines are those lines operating in voltage range Several parts of an overhead transmission line have to be included in a model adequate for lightning overvoltage studies;
extra- high voltage (EHV) lines are those lines operating at voltages in the range 345 765kV;
ultra- high- voltages(UHV) lines are those proposed for operation in the range 1000 1500kV.

Lightning is one of the main causes of electric power system fault. It is well known that the entire power system consisting electrically of power plants, substations, transmission lines, distribution feeders and power consumers. Generally, the Power Grid or Electric Power Network referred to that part of the electric power system except the power plants and consumers. All components of the power system form an organic whole and maintenance the dynamic balance in operation. The system frequency, voltage, tie-line flows, line currents and equipment loading must be controlled and kept with limits determined to be safe. Lightning, especially Cloud-to-Ground (CG) lightning could damage power transmission lines, distribution lines, substations and power plants. Furthermore, such hazard may lead to loss of the system stability and uncontrolled separation of power network even threatens the whole electric power grid.

1.1.1 Lightening

Lightning is an electrical discharge between cloud and the earth, between clouds or between the charge centers of the same cloud. Lightning is a huge spark and that take place when clouds are charged to at a high potential with respect to earth object (e.g. overhead lines) or neighboring cloud that the dielectric strength of the neighboring medium(air) is destroyed.[3]

1.1.2 Types of Lightening Strokes

There are two main ways in which the lightning may strike the power system . They are

- Direct stroke
- Indirect stroke

1.1.3 Direct Strokes

In direct stroke, the lightning discharge is directly from the cloud to the an overhead line. From the line, current path may be over the insulators down to the pole to the ground. The over voltage set up due to the stroke may be large enough to flashover this path directly to the ground. The direct stroke can be of two types
1. stroke A
2. stroke B
In stroke A, the lightning discharge is from the cloud to the subject equipment(e.g. overhead lines). The cloud will induce a charge of opposite sign on the tall object. When the potential between the cloud and line exceed the breakdown value of air, the lightning discharge occurs between the cloud and the line.
In stroke B the lightning discharge occurs on the overhead line as the result of stroke A between the clouds. There are three clouds P,Q and R having positive, negative and positive charge respectively. Charge on the cloud Q is bound by cloud R.

If the cloud P shift too nearer to cloud Q,Then lightning discharge will occur between them and charges on both these cloud disappear quickly. The result is that charge on cloud R suddenly become free and it then discharges rapidly to earth, ignoring tall object.

1.1.4 Indirect strokes

Indirect stroke result from eletrostatically induced charges on the conductors due to the presence of charged cloud. If a positively charged cloud is above the line and induces a negative charge on the line by electrostatic induction. This negative charge however will be only on that portion on the line right under the cloud and the portion of the line away from it will be positively charged. The induced positive charge leaks slowly to earth. When the cloud discharges to earth or to another cloud, negative charge on the wire is isolated as it can not flow quickly to earth over the insulator. The result is that negative charge rushes along the line is both directions in the form of traveling wave. Majority of the surges in a transmission lines are caused by indirect lightning stroke. accordingly, the more frequent threat of lightning hazards will become. Furthermore, the more serious destructive consequence would be than ever before.

1.2 Why we need protection from Lightening?

Electricity is modern societys most convenient, useful and important form of energy. Without it, the present social infrastructure would Without it, the present social infrastructure would not at all be feasible. Furthermore, we also couldnt imagine our working and living without communication system and electronic devices nowadays. The more our life depends on electric power, communication, and electronic systems,[9]

1.2.1 Lightning hazards to Power Grid

Lightning is a significant cause of electric power system fault. It is well known that typical Electric Power System includes power plants, power grid (power network) and power consumers. And the power grid consists of transmission network and distribution network.

1.2.2 Lightning hazards to Substations

When lightning strikes a phase conductor of transmission line, the current of the lightning stroke will encounter the surge impedance of the conductor so that overvoltage will be built up and propagate to the substation along the transmission line in wave form. This lightning incoming wave would damage the electrical equipments and facilities in substation.

1.2.3 Lightning hazards to Power Distribution system

The principal mechanism of lightning flashover on HV, EHV and UHV transmission lines are the shielding failure and the backstroke events due to direct stokes. For the lower high voltage and distribution lines, the induced voltage accompany strokes close to the line predominantly ontribute lightning overvoltages. Lightning damages to the power distribution system are a serious problem to many utility-systems and account for the majority of consumer outages causing the highest expense in breakdown of distribution equipment.

1.2.4 Attachment of lightning flashes to grounded structures :

As a stepped leader approaches the ground, the electric field at the extremities of grounded structures increases to such a level that some of these structures or different parts of the same structure may launch connecting leaders towards the down-coming stepped leader. The first return stroke is initiated at the instant contact is made between the down-coming stepped leader and one of these connecting leaders. The strike point of the lightning flash is the place from which the connecting leader that made the successful connection to the stepped leader was initiated.

An exact evaluation of the point of lightning strike of a structure should take into account the development of streamers from the extremities of the structure, the sub-sequent streamer-to-leader transition, the inception of a stable propagating leader and the final encounter between the upward-moving connecting leader and the down-coming stepped leader. However, current international standards on lightning protec- tion of structures and power transmission and distribution lines are based on different concepts and models, namely the protective angle method and the electro-geometrical method (of which the rolling sphere method was a derivative); these neglect most of the physics associated with the attachment process of lightning flashes with structures. However, lightning research has progressed significantly over the last several decades, resulting in a deeper understanding of the physics of the process of attachment and the possibility of representing this physics in computer simulation procedures. Today, the possibility exists of simulating the inception and propagation of leaders from grounded structures under the influence of down-coming stepped leaders, so that the point of lightning strike of any complex structure may be predicted.

1.3 Objectives of this Project

The main purpose of this project is to study the existing overhead transmission line shielding structure and about to performing the analysis work for existing shielding structure to figure out the best possible shielding angle and structure height which will be beneficial for overhead transmission lines to withstand in lightening (i.e. protection from lightening)

1.4 Suggestion for further research

A critical review of recent years papers on lightening and on the general performance of transmission lines in perticular suggest a number of ares of uncertainity required sustained or even accelerated research. Among these areas :[1]

1.4.1 Ground flash density

The ground flash density, Ng, is the basic parameter of most quantitative studies of lightening effects, not only on electric-supply lines, but also for structural protection and insurance problems. Extensive Studies have been in the Progress in many countries through the world.while formidable difficulties have been encountered, largly because of varying meterological conditions, substential progress has been made.

1.4.2 Non linear Grounding System

Additional studies of non-linear grounding systems using much higher impulse currents should do mush to improve the analytical Models used to describe this phenomenon.

1.4.3 Critical Flashover Voltages for Non-standard Wave-shapes

while some progress has been made with respect to flashover voltages for non-standard wave-shapes, and recent laboratory studies clarify the mechanism of the long spark, additional studies of the type carried out by Caldwell and Darveniza (1973) would be helpful.

The late Charles F. Wagner once remarked that
The lightening experts should have his head in the clouds and his feet on the ground,
meaning that all our theories and analytical models, however well conceived,must meet the final test compability with the actual performance of the lines we designed. Hopefully, the reader may have found something of this philosophy reflected here.

Chapter 2

Actual phenomenon of Lightening Thunder:

Experimental investigations show that a negative downward lightening flash is initiated ba a column of negative charge called the negative stepped leader that travels from cloud to ground in a stepped manner. As the stepped leader travels towards the ground , the electric field produced by the stepped leader at ground level increases steadealy. Due to field enhancement, the electric field at the pointed tips of the grounded structure which is immersed in this background electric field may reach the values which are several times to several ten times the magnitude of the background electric field produced by the stepped leader. When the electric field at the tip of a structure reaches a critical value, an upward positive leader discharge incepted from the structure. This, leader created by the action of action of the electric field generated by stepped leader is called connecting leader. Once incepted, the connecting leader starts to grow towards the down comming stepped leader. Both the connecting leader and the down comming stepped leader propagate with the aid of streamer discharges generated from their tips. As the connecting leader approaches the negative stepped leader the average potential gradient between the two leader tips continues to increase and when it reaches a critical value the final connection between the two stepped leaders becomes imminent. This condition , i.e. The average potential gredient between the two leader tips reaching a critical value, is called the final jump condition. Once the connection is made between the two leader, the resulting rapid neutralization of the stepped leader charge leads to generation of return stroke. The point of attachment of the downward negative lightening flash on the structure is the point of initiation of the connecting leader that made the final connection with the stepped leader.[4] According to IEC standard the radius of the rolling sphere that is being used in the installation of lightening protection systems on structures is given by

$R = 10Ip^{0.65}$..(1)).

where Ip is the peak current of the prospective return stroke. Even though it is not stated specifically in the standard, the method of rolling sphere implies that a stepped leader having a prospective return stroke peak current Ip, will be attracted to the structure when tip of stepped leader approaches the structure within a critical distance of R. Though not mentioned specifically in the standard this is exactly the geometrical defination used in the electro- Geometrical Method (EGM). For this reason, we treat Eq. (1) as the variation of the striking distance as a function of return stroke peak current as assumed in the IEC standard.

2.1 Modes of lightening flashover

For the practical study of the lightening protection and performance of transmission lines, it is convenient to define three modes or mechanism by which the lightning strokes can cause insullation flashover. Although related phenomena can be found in all three modes, they wil be considered as essentially independent unless otherwise noted.[1]

1. The induction (IN) mode is operative for strokes to earth near the line but not in contact with any element of it.

2. The shielding failure (SF) mode is operative for strokes directly to the phase conductor .

3. The back flashover (BF) mode is operative for for strokes directly to the shield wire or supporting structure.

The induction mode is now quite generally considered harmless to the transmission lines .induction mode mechanism could be protected against and and that direct strokes were certain to result in flashover on steel-tower lines and massive structural damage on wooden pole lines. Creighton(1922) explored the economic value of the overhead static wire , and concluded that it was beneficial on steel towers but harmful on wooden pole structures.

With the advent of the cathode-ray oscillollograph and the initiation of large field research programmes it became possible to access the relative roles of

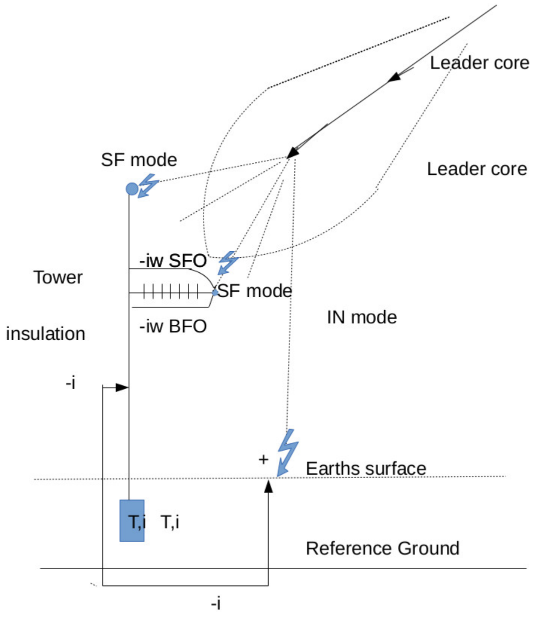


Figure 2.1: Modes Of Lightening Flashovers

the IN and BF modes of flashovers objectively. Extensive studies in Europe and united states led to conclusion that the IN mo0de was negligible in causing lightening outage on HV lines (Fortescu, 1930; wagner and McCann, 1942). Figure 1 illustrate the lightening modes of flashovers on the transmission lines.

Chapter 3

Important Parameters of Lightening Protection

1) The Electric field under a leader channel
2) The Striking Distance [1]

3.1 The Electric field under a leader channel

The magnitue of the electric field strength at the earths surface is well established, both in fine weather and during the passage of a thundercloud (chalmers, 1967). It is customary to express this magnitude by its vertical component on the assumption that the earth constitute a good conductor.The electric field-charges produced at various distances from the leader strokes can be well analysed. The field gradient below a leader channel will now be explained.

Consider a negative cloud charge Q at a height H above the ground and further charge q distributed along the leader channel, the tip at which is at a height above the ground h. The field at a point near a ground level is then function of magnitude of Q and Q and variation of charge density along the leader channel.It canbe shown that the charge Q contributes little to the electric feildonce the leader has been progressed along most of its trackto ground so that its effect can be neglected, at least over open territory. The magnitude of Q and q involved in the earth flasheshare reasonably well accepted.. assuming earth to be an ideal conductor so that the ideal theory of image can be applied, the calculation of the electric field then followed standard electrostatic considerations. The only major difference in the results obtained by different investigations are therefore due to varying assumption on the distribution of charge density along the leader channel. Wagner and McCann (1942) assumed the uniform charge distribution ; in this

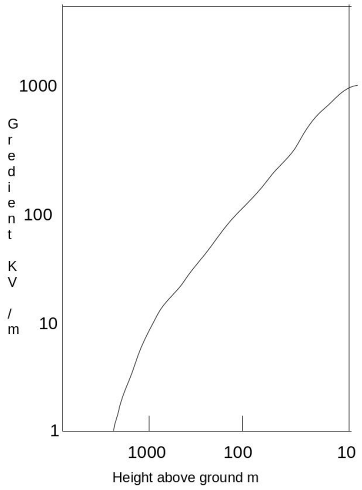


Figure 3.1: Fig. Electric field Grediant below leader Channel a) fun. Of horizontal distance

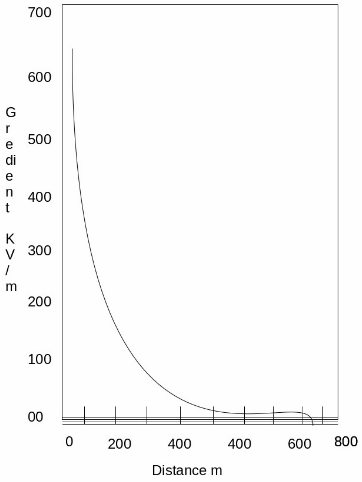


Figure 3.2: Fig. Electric field Grediant below leader Channel b)fun. Of leader tip above ground

assumption they were followed by most other workers. In contrast, Bruce and Golde (1941) argued that the charge distribution must be such as to produce a fairly uniform potential drop along the channel.and it was therefore suggested tha tthe charge is highest at leader tip and that is decrease exponentially toards the cloud. This assumption was then supported by measurement in the electrolytic tank.

Aderson (1973) explained the effect of different charge density distribution on the resulting field gradients and compared this with field records. Ii is suggested that the wave-front of the current in the return stroke is greatly effected by capacitance to the earth of the lowest sections of the leader channel and any low branches, as well as by the mutual capacitance between such branches and the main channel. This would firther complicate the charge- density distribution behind the tip of the leader. Golde maintained the assumption of an exponential charge distribution to determine the attractive effect of the lightening. The electric field strength below a point charge Q at a height H abive an ideal earth is

$$E = \frac{(1.8 * 10^{10} Q)}{H^2} V m^{-1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2))$$

Equation (2) shows that the field is inversly proportional to the square of the height of the charge and, this implies that the natural lightening leader would have to approach much nerear to earth than the leader in a much shorter laboratory spark before an upward streamer was likely to be initiated. Equation (2) was further developed (Golde, 1945) for lightening leader and fig 2(a) and (b) apply to vertical leader above flat ground. In the presence of a lightening rod the electric field about the rod is grossly distribution was determine by Larmor and Larmor(1914) by replacing a thin rod by a semi-ellipsoidal shape

3.2 The Striking Distance

The information represented now be used to determine the attractive effect of a vertical lightening rod. As shown vidly by the rotating- camera photograph obtained by Malen can be taken as established that the leader stroke proceeds towards earth down to the penultimate step unaffected by any failure on, or below, to the earth surface. The last step thus effects the meeting between the downward moving leader and streamer growing upwards from earth (The final jump). During the leader progress the electric field strength between the tip of the leader and earth increases as indicated in Figure 2. A series of curves therefore constructed in which the field strength below the leader was plotted against the height above the ground of the tip of the leader for different values of the charge deposited on the leader channel.[1] The striking distance was taken to be that height of the leader tip above ground at which a critical down strength was reached across the final air gap. For this purpose a critical assessment was made of the test result reproduce and it was concluded that this critical breakdown gradient amounted to

$$300kVm^{-1}$$

for the normal negative lightening stroke and

$$500kVm^{-1}$$

for the rare positive stroke. With these assumptions curves (1) in fig.3 was derived for predominent negative flash . It shows the variation of the striking distance with the current in the return stroke which was return stroke proportional to the charge on the leader on the basis of 1C being eqivalent to a current of 20kA. Similar analyses were presented bySchwab(1965) and Braustein (1970).

Some of the assumptions , The claim of a direct proportionality between the current in the return stroke and the charge on the leader has been recently confirmed doubt which has been expressed concerning such a co-relation appear to have overlook the fact that the electric gradient under the leader is mainly due to the charge on the leader not those left in the cloud. The first return stroke reches the ground sum tens of micro seconds after its initiation.

Namely at a time when the current has fallen to about half its crest value. It is roughly the charge in this impulsive part of the current which is shown, from the results discussed, to statistically co-related with the current amplitude so that this particular assumption must be dimmed valid.

The one as mentioned, Negative charge of IC was being equivalent to 20 kA. However it is obvious from electrostatic consideration and calculation that, even with a uniform charge density, made to the electric gradientbelow the leader tip by the charges on the channel decrease rapidly from leader tip to higher sections. With an exponential of charge density this effect is further enhanced. It may thus argued that only the fraction of impulsive charge is responsible for the greater part of electric field by which he striking distance is determined . A further factor which is open to review concerns the critical breakdown strenghts of

$$500kVm^{-1}$$

for positive impulse . This method of estimating the attractive radius was developed as one aspect of comprehensive review of the mechanism of the lightening discharge and its effect on trans,mission lines and other structures .on the basis of potential with respect to earth of the leader tip was calculated. The critical breakdown strength before contact was established between a downward leader and an upward streamer was given as between 500 and

$$600kVm^{-1}$$

This led to curve(2)in fig(3)and to the relation

$$r = 2 * 10^2 \frac{v}{1 - 2.2v^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3))$$

where r is the striking distance in m and v is the velocity of the return stroke as percentage of the velocity of light, the velocity v being uniquely associated with the amplitude of the current in the strok. Striking distance were increased to about 40m for a current of 10kA and about 100m for 50kA.

Davis (1962) also calculated the potential of the leader tip by assuming a uniform charge distribution along the leader channel. He further took the average negativ impulse breakdown voltage in a point- plane arrangement to follow a simple numerical law as a function of the flashover distance. By plotting this relationship and the average gredient between leader tip and earth as a function of the height of the tip above ground, striking distance were determined. Only three values are, quoted, based on the assumption of the current 0f 100kA being associated with a charge of 5C. They are indicated in fig.(6) by crosses.

It must be emphesized that all the proposed solution presented in this section must be regarded as approximate. All methods start from a gross simplification of the physical nature of the lightening discharge. Some of the specific assumption ade by individual investigators have been mentioned, others are common to all solutions, e.g. that of vertical lightening channel, the neglect of branches and space charges, and the condition of ideally conducting earth. Neverthless it is important to note that all solution leades to the same basic solution concerning the attractive effect of a lightening conductor. In perticular they agreed that the striking distance is short compared with the length of the lightening path. They also Showed that ot is not a constant size, as once thought, but that it is a function of the intensity of the lightening strike. Thus for a week stroke, the attractive effect may may be too small to prevent a strike to a point close to a conductor or even to apoint below the tip of lightening rod.
Additional support for short striking distances can be addused from rotating-camera photograph (Schonland and callens, 1934 malan and callens, 1937). All these flashes occurd to the open African veld where the lower cloud level is at height of 2km. Photograpfs of nine first strokes showed that at height varying from

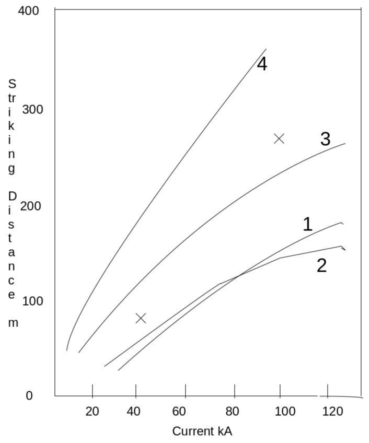


Figure 3.3: Fig. Variation of striking distance with negative lightening current

46 to 268m, with an average of 180m. At the point where these branches form, the leader stroke proceeds downward towards ground. In this case the striking distances occasionally indicated by sharp kinks, must therefore be considerably shorter than the height indicated by the forgoing measurements.

3.2.1 Analytical expression for striking distances

The electrical transmission engineer requires numerical information on the striking distances for two reasons. It determines the area over which lightening flashes of different intensity are attached to an overhead line and it assist in solving the question of protective effects of an overhead fhield wire is equivalent to a horizontal lightening conductor. Investigation to adetermine the striking distance to transmission lines .[1]
Armstrong and Whitehead (1968) were the first to develop an analytical expression of the form.

$$r = ki^p m\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

where r is the stkriking distance, k and p are constants and i is the amplitude of the current in the return stroke. They determine values by theriotical approach by Wagner(1963) the justification for any analytical approach can only lie in describing actual line performance. With this view in mind, a research program was initiated to record the performance of the HV transmission lines.

All energy paremeters and the striking distances are inter-related in complex manner. In order to arrive at simple expression for the striking distances, the various relationship were taking into consideration. Additional assumption were introduced. Firstly it was assumed that the radius of corona sheath increased up to avalue when ionizing gradient was reached at its surface. Secondly, the radius of the return stroke-channel was taken to increase untill the current density assumed a critical value. And , most importantantly , the critical Breakdown grediant was taken to be determined by the swiching impulse strength. Two arithmetical expression were thus derived for the potential of the leader tip, describing the potential as function of on the one hand , the striking distance and , on the other hand, the radius of the corona sheath.

Love (1973), done the computer analysis , emphesized that the numerical values obtained for the striking distance developed on the values adopted by Wagner for energy dissipated during the transition from leader to return stroke channel . Love explained the effects changes in the energy constant on the striking distance but found it to be of limited significance. The relationship was :

$$r = 2i_0 + 30[1 - exp(i_0/6025)]................................(5)$$

with

$$r = vcq$$

In which , according to Wagner (1963), vc is the velocity of the return stroke and q is the charge density on the leader. For the purpose of practical calculation, Expression (4) were replaced by

$$r = 10i^{0.65}m.................(6))$$

3.2.2 Effect of height of structure on striking distance

If the lengthof the earthed electrode of a rod-rod gap is short compared with the flashover distance, its switching impulse break-down voltage is practically the same as that of a rod-plane gapof the same dimmenssion. It is concluded that the striking distance between the tip of a leader channel and a low structure would be the same as to open ground. However, the greater heights, it must be concluded that the striking distance for the predomonant negative lightening strokes should increase with increasing structure height.[1]

The average length of a step in the lightening leader is of the order of 20m although the Mallen (1963) found that this length increased as the leader approaches the open grond. Scholand (1956) quotes a length of 50m and adds that this increases with increasing velovity of the leader.

$$r = 2i_0 + 30[1 - exp(i_0/6025)]................................(5)$$

In this circumstances the numerical results obtained cannot, strictly sparking, be applied to structure mote than the few tens of structure heih. This is largly due to intense distortion of the electric field around a tall vertical conductor. The increase in this grediant a multiple of the grediant at ground level is calculated by Aderson(1970) as a function of structure height.

The point discharge current which would flow into the atmosphere from the tip structure of different .by applying the method of eq.(3) can be determined the striking distance as the structure height for five values of the critical glow-to-arc transition current. For a current of median amplitude ,found that for structure height of 200 to 300m height, the striking distances can be unmounted to about 2km which explained occurance of upward flashesh from tall structure. There is a further effect which is likely to have a bearing on the striking distances to a tall structure. Point discharge currents of several milliamperes can flow for lengthy period from a tall tower into the atmosphere. The resulting positive ion drift towards the thundercloud under the influence of prevalence electric field.this ionic stream will be deflected and broken up by the strong wind which is associated thunderstorm condition. Pockets of positive space charge are believed to guide the leader stroke and in the words of Wagner (1963), sometimes produce rather bizzare effects on the path of leader over a distance which may be considerably larger than its last step. If such a guilding effects exist the distance at wich it should be applied will not be equated. With the striking distance defined in this survey. It is concievable that th

$$r = 2i_0 + 30[1 - exp(i_0/6025)]................................(5)$$

is effect was operative in lightening photograph. Described by Errikson (1974).he measured the striking distance from that point at which the direction of discharge pathfirst assumed a non-random and persistance orientation. toward the top of a 60m mast on which the photography was obtained. In this cace the current of 41kA was recorded and the striking distance was estimated as around 300m. No objection can be raised aginst the careful analysis although Erikcon himself described a second piont of the deviation in the path of the flash at the distance of about 120m from the tip of the tower. More evidence clearly required before his distance of stEquation (2) shows that the field is inversly proportional to the square of the height of the charge and, this implies that the natural lightening leader would have to approach much nerear to earth than the leader in a much shorter laboratory spark before an upward streamer was likely to be initiated. Equation (2) was further developed (Golde, 1945) for lightening leader and fig 2(a) and (b) apply to vertical leader above flat ground. In the presence of a lightening rod the electric field about the rod is grossly distribution was determine by Larmor and Larmor(1914) by replacing a thin rod by a semi-ellipsoidal shape riking distance can be accepted.

Two photograps are available from Mount San Salvator in which the striking distance can be correlated with the current amplitude. In this Rotating-camera Photographs the height of the last leader step above the tower indicates the instant when an upward streamer was initiated. In the first case , a negative current amplitude of 16kA was associated with a distance of 27mand, in the second case, a negative current of 27kA gave striking distance of 37m.

Chapter 4

Protection Against Shielding Failure

Shielding failure has been recognized as a possible mode of lightening flashover, butuntill about 1960 it was not considered a substential one. The fact that many lines were effectively shielded appears to have good stemmed insulation, and it is fortunate indeed that this was the case since, inrescent experimental and stastical studies, samples of good and bad insullation were available for analysis.[1]
The lightening performance of first EHV (345kV) lines in the united state, designed for an outage rate of less than 0.3 per 100 km-yr in accordance with the estimates made by the methods of A.I.E.E. Report (1950), was astongnishly poor. Outage rates in the range of 4-6 per 100km-yr were experienced. Ensuring studies were initially confined to those who assuming effective shielding, and advanced field theory concept were employed to descover the reason for excessive Backflashover rate. These efforts, while producing better understanding of the basic concept of underlying the response of the toer and conductor to the forcing lightening current, failled to resolve the dilemma of the so-called anomalous outage rate.

Following the failure, attention was redirrected towards the problem of effective shielding, based on modern knowledge of the lightening stroke. It was correctly assumed that , in the case of strokes to the phase conductor the leader must come within only a few decameters of the tower top before the actual point to be struck is determined. This distance has been variously called the last step, the final jump and the striking . The last term will be used here. The determination of this distance is essential to the development of various electrogeometric theories agree in the main concepts but may differ substentially in detailled development. Others are derived from stastical analysis of line performance and are only interferntially related to the stroke mechanism.

4.1 Recent techniques used in transmission line protection

4.1.1 Artificial Neural Network Approach

The reach accuracy of an electromechanical, static or a microprocessor based distance relay is affected by different fault conditions and network configuration changes. So ANN techniques are under investigation over the past 15-20 years, which can adapt dynamically to the system operating conditions at a high speed. The ability of ANN to learn by training any complex input/output mapping and recognize the noisy patterns (those with desired segments missing and/or undesired segments added) gives them the powerful property of pattern recognition and classification (Haykin, 1994). ANNs can solve the overreach and the under reach problems which are very common in the conventional distance relay design. ANN utilizes samples of currents and voltages directly as inputs without computation of phasors and related symmetrical components. Various kinds of neural network such as multi-layer perceptron (MLP), recurrent, radial basis function (RBF), probabilistic neural network etc. are being applied for fault classification and fault location. These are designed by different training algorithms like back propagation, orthogonal least square, extended kalman filter etc.. The use of ANNs can extend the first zone of distance relays and enhance system security (Coury et al., 1998). For selecting the appropriate network configurations, the performance criteria are fault tolerance, minimal response time and generalization capabilities. ANN approach has been used to improve some of the standard functions used in protection of transmission lines. They have been related to fault direction discrimination (Sidhu et al., 1995; Sidhu et al., 2004), fault detection and classification (Dalstain et al., 1995; Kezunovic et al., 1996; Sanaye-Pasand et al., 2006; Jain et al., 2006; Couryet al., 2002), distance protection (khaparde et al., 1991; Coury et al., 1998; Cho et al., 1999), improvements in fault distance computation (Bouthiba, 2004; Zahra et al., 2000; Chen et al., 2000; Purushothama et al., 2001; Tawfik et al., 2001; Ekici et al., 2009), protection of series compensated lines (Novosel et al., 1996), adaptive distance protection(Khaparde et al., 1996; Jongepieret al., 1997; Bhalja et al., 2007; Aggarwal et al., 1999) and adaptive reclosing (aggarwal et al., 1994).

To make the ANN responsive to time varying voltage and current waveforms different types of recurrent networks were considered that allow the hidden units of the network to see their own previous output, so that the subsequent behavior can be shaped by previous response. Such an Elman recurrent network designed to act as the fault direction detection module of a transmission line is proposed by Sanaye-Pasand et al., (1998), Sanaye-Pasand et al., (1999). Inside these ANNs the operations that take place are not clearly defined and hence they are not considered highly reliable. Further development is the concept of supervised clustering to reduce the number of iterations in the learning process of multi layer feed forward networks (Kezunovic etal., 1995). A neural network simulator is developed by Venkatesan et al., (2001), to identify the optimum ANN structure required for training the data and to implement the ANN in hardware. Still the problem with ANNs is that no exact rule exists for th choice to the number of hidden layers and neurons per hidden layer. So it is uncertain whether the ANN based relay gives the optimum output, to maintain the integrity of the boundaries of the relay characteristics. A high speed distance relaying scheme based on radial basis function neural network (RBFNN) is proposed by Pradhan et al., (2001), due to its ability to distinguish faults with data falling outside the training pattern. A sequential procedure is presented by Dash et al., (2001), for distance protection using a minimal radial basis function neural network (MRBFNN), to determine the optimum number of neurons in the hidden layer without resorting to trial and error. The use of separate ANNs, for faults involving earth and not involving earth has proved to be convenient way of classification of transmission faults based on RBF neural networks by Mahanty et al., (2004). For simple and reduced architecture and better learning capability a modular neural network, is proposed by Lahiri et al. (2005), Pradhan etal., (2001) to discriminate the direction of faults for transmission line protection. Such a network considers corresponding phase/ground voltage and current information as input and thereby the redundant inputs in conventional approaches are eliminated.[4]

The existing ANN based solutions easily converge on local minima whenever input patterns with large dimensionality are present and when designed for specific applications, are prohibitively expensive or infeasible for real time implementations. It is observed that the ANN based distance relays need much larger training sets and hence the training of these networks is time consuming and further research work shall produce a hardware realization with proper modification in the learning methodology and preprocessing of input data that would improve the learning rate performance, efficiency and the reliability many folds. Presently research efforts are in the direction of evolutionary computational techniques such as genetic algorithms (GA) for determining the neural network weights and thereby avoid training of ANN.

4.1.2 Fuzzy Logic and Combined Neural Network/Fuzzy Logic Approach

Zadeh introduced the concept of fuzzy set theory in 1965 for dealing with uncertain and ambiguous properties of events (Zadeh, 1965). It was introduced in power system networks to solve uncertainty problems that arise due to the continuously varying power system parameters. The key benefit of fuzzy logic is that its knowledge representation is explicit, using simple IF-THEN relations. The fuzzy set theory is used for fault type identification on a transmission line by Ferrero et al., (1995), Das etal., (2005), without any computationally expensive training of ANN or expert domain knowledge. These algorithms are fairly accurate only under certain assumptions of fault distance, prefault power flow, fault resistance and line length. Fuzzy sets are good at various aspects of uncertain knowledge representation, while neural networks are efficient structures capable of learning from examples. Neural network has the shortcoming of implicit knowledge representation, whereas fuzzy logic systems (FLS) are subjective and heuristic. In a fuzzy neural network (FNN), a neural network is used to implement a fuzzy rule-based system from input/output data to enhance the learning capabilities, plus knowledge illustration of fuzzy logic system. Wang et al., (1998), proposed three different neuro-fuzzy networks in series to classify the fault in transmission line protection using both designers experiences and sample data sets. A distance relaying scheme based on FNN is proposed by Dash et al (2000) in which the fuzzy view point is utilized to simply the model, but the FNNs calculate the fault distance within 80 percentage of the line. A new concept of transmission line fault classification algorithm using a self-organized neural network based on adaptive resonance theory (ART) with fuzzy K-nearest neighbor (K-NN) decision rule is proposed by Vasilic et al., (2005), to improve algorithm selectivity for avariety of real events not necessarily anticipated during training. An algorithm is developed by Yeo etal., (2003), using the adaptive network-based fuzzy inference system (ANFIS) for fault detection and classification in transmission lines based on root mean square value of phase current and zero sequence current, under a wide variety of system and fault conditions including contingencies such as high impedance faults. In fuzzy logic based protection system, accuracy cannot be guaranteed for wide variations in system conditions. So consequently a more dependable and secure relaying algorithm during real time implementation is needed for classifying the faults under a variety of time-varying network configurations. The fuzzy-neuro approaches are sensitive to system frequency changes and require large training sets and a large number of neurons affecting their accuracy and speed in protecting large power networks.

4.1.3 Surge Arrester

Surge arresters (or lightning arresters or surge diverters) are installed on transmission lines between phase and earth in order to improve the lightning performance and reduce the failure rate. Surge arresters are semiconductors with nonlinear resistance from a few to several . Several different types of arresters are available (e.g. gapped silicon carbide, gapped or non-gapped metal-oxide) and all perform in a similar manner: they function as high impedances at normal operating voltages and become low impedances during surge conditions. Even though a great number of arresters which are gapped arresters with resistors made of silicon-carbide (SiC) are still in use, the arresters installed today are almost all metal-oxide (MO) arresters without gaps, something which means arresters with resistors made of metal-oxide . An ideal lightning arrester should:
(i) conduct electric current at a certain voltage above the rated voltage;
(ii) hold the voltage with little change for the duration of overvoltage; and
(iii) substantially cease conduction at very nearly the same voltage at which conduction started .[6]
The main characteristics of a surge arrester are:

- maximum continuous operating voltage (MCOV), which must be greater than the
- maximum network operatingvoltage with a safety margin of 5 percentage;
- rated voltage, which must be1.25 x MCOV;
- protection level;
- capacity to withstand the energy of transient overvoltages

The lightning energy E (in Joules) absorbed by an arrester is computed by the relation:

$$E = \int_{t0}^{t} u(t).i(t)dt................(7)$$

where:
u(t) is the residual voltage of the arrester in kV and
i(t) is the value of the discharge current through the arrester in Ka.
When the absorbed energy by the arresters exceeds their maximum acceptable level of energy, then they will fail(damage). Assuming that surge arresters are the last protection measure of a transmission line, an arrester failure is considered as a line fault. The arresters failure rate is given as :

$$FR = NgL[(\int_{Tb}^{\infty}\int_{I_AI_t}^{\infty} f(I_p*h_A)d(I_p)y(t)d(T_A))+(\int_{Tb}^{\infty}\int_{I_BI_t}^{\infty} f(I_p*h_B)d(I_p)y(t)d(T_B))]$$

where:

$I_A(T_t)$ is the minimum stroke peak current in kA required to damage the arrester, when lightning hits on a phase conductor, depending on each time-to-half value,

$I_B(T_t)$ is the minimum stroke peak current in kA required to damage the arrester, when lightning hits on the overhead ground wire, depending on each time-to-half value,

$f(I_P)$ is the probability density function of the lightning current peak value, $g(T_t)$ is the probability density function of the time-to-half value of the lightning current,

FR is the arrester total failure rate, N_g is the ground flash density in flashes per km^2 per year and L is the line length in km.

4.1.4 Block diagram of essential elements for Protection of Transmission line from Lightening

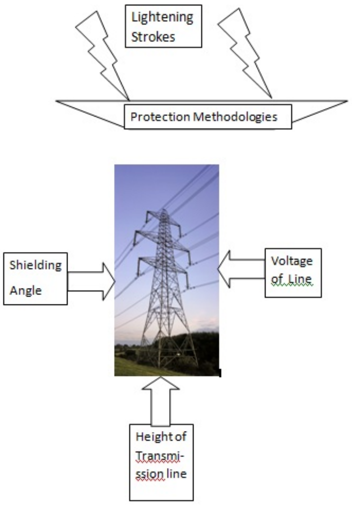


Figure 4.1: essential elements of protection

4.2 Approaches to the Estimation of Lightening performance of lines

4.2.1 Lightning Outage Estimation Methods

Methods of estimating the lightening performance of transmission lines require extention of analytical modelfor the back flashover mode of insulation flashover to include substistical distribution of current wave-shapes, grounding parameters leader approach angle and flashover density. Moreover shielding failure outage must alsobe estimated. Such an extenssion is beyond the scope of thios chapter, but it will be useful in the outline the approaches.

The utility transmission engineer is vitally concern with providing a level of transmission line reliability consistent with the load capability of the line and its role within the transmission network, to provide an estimate of this reliability with perticular referance to lightening hazard, lightening specialist have devised various system of estimating the lightening outage rate for proposed lines to operate in a specialised environment.

4.2.2 The A.I.E.E. Method

The A.I.E.E. Committee report(1950) was based on the work of Harder and Clayton (1950) with the exceptions that a 4/40 micro second wave-shape was selected as representative of higher lightening current required for insulation flashover. The resulting Wave-shapes of voltage across the insulation were determined for various span length and ground resistance by injection of the current wave into a model transmission line and measurement of the voltage by a cathode-ray oscilloscope. This analog computing system was called the Anacom method. Shielding was considered effective ; with only 0.1 percentage of the stroke assumed to result in stroke to the conductor. This assumption lay at the root of the puzzeling result that the method predicted the performance of the some lines with uncanny accuracy, while failing completely for others.

4.2.3 A Modernise Version of A.I.E.E. method

Clayton and Young (1964), taking the advantage of improved concept developed over the interverning years, modernized and extended the basic ideas of the A.I.E.E. report and recommended separate studies to determine shielding requirements. Wave-fronts of 2, 4 and 6 micro seconds were employed instead of a single value for this parameter. System voltages was taken into consideration and the response of counterpoises was studied by means of an analog circuit made up of pi sections. This estimation method was used very successfully in the design stages of a EHV transmission lines.

4.2.4 Method of Limiting Parameters

Based on the work of Razevlg (1959), Alizade et al. (1968) and others, Popolansky has applied this method in Popolanasky (1970) and in Darveniza et al. (1975). The method employs independent current amplitude and current steepness frequency distribution with ground resistance value serving to define boundries between amplitude and steepness resulting in insulation flashovers and region which do not. Shielding- failure outages are estimated as a friction of the strokes attracted to the line using the method of Burgsdorf (1969).

4.2.5 Monte Carlon Methods

Monte Carlo methods derive their name from the random selection of a defined set of parameters constituting a trial, followed by the use of set of this parameters in an analytical model to determine theoutcome of trial. The process is applicable to shielding failure as well as the back flashover mode of insulation flashover. Since there can be a large number of frequency distribution involved, a correspondingly large number of trials is required to reach convergence of the outage rate. Such methods clearly require the use of computers having memmories and programming flexibility.

Chapter 5

Analytical Model of generally used Transmission Line

Shielding-failure flashovers can be reduced to rare events by providing properly shielding comductors. Even poorly located shields wires failed to intercept some of the strokes to the line and even poorly located shield wires intercept most of the strokes to the line and even popularly located shield wires failed to intercept some of the strokes having prospective currents to earth above minimum amplitude the design problem then consist of steps required to locate the shield wires son to intercept strokes having prospective currents to earth above minimum amplitude. It is convinient to an analytical model which exhibits the relations between the structural and electrical parameters of the problems. In such a model, the mean structural dimmenssion of the of the line together with the means of striking distance of the stroke constitute the geometrical parameters. It is desirable that the the base case of reference model be assimple as possible , yet yet provide for deviations from reference assumptions by means of fig (A), adopted from Gillman and Whitehead (1973) , illustrate the principal geometrical features . The complete analytical model consist of geometry together with an associated set of basic assumptions and mathematical relations .[1] and[5]

(a) The mean conductor height can Hg can be computed from the profile Drawings or, alternatively, estimated for primainary purposes from the following relation : Hg =Hgt-(2/3)(Sc)
Hgt= height of conductor at the tower ,
Sc= sag of the conductor;
rolling profile
Hgr=Hgt; mountaneous profile
Hgm=2Hgt; for all cases

$$Hg = Hp + \Delta$$

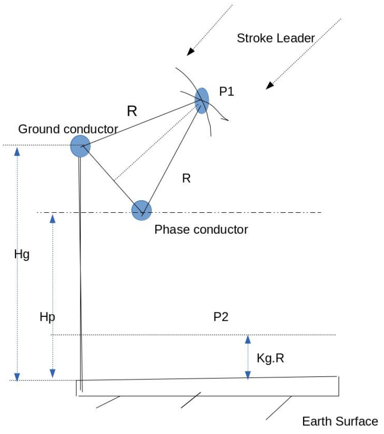


Figure 5.1: Analytical model of transmission line

Hgt = height of the dhield wire at the tower
Ss = sag of the shield wire (b) The mean Spacing between the phase conductor and the shield wire can be estimated from a preliminary configuration. If none are yet avilable an estimate of

$$C = U(50percent)/145m$$

may be used for initial studies (c) The striking distance to be used is the value corresponding to prospective current to earth of

$$Ioc = 2.2U(50percentage)/ZckA.$$

$$U(50percentage) = criticalimpulseflashovervoltageoftheinsulation(kV),$$

Zc = surge impedance of the comductor in the presence of shield wires (ohm). (d) The striking distances are given by

$$R = 10Ip^{0.65}..........(accordingtothestandardIEEEmodelofTransmissionline)$$

As leader immerges to transmission line protective theory says that the Both Ground wire and Phase conductor produces protrctive arc around them. This protective arcs cuts each other in space at a point terminating point. The termination point of a lightning stroke to a transmission line can be a ground wire, a phase conductor, a metal tower or even the ground. According to the electro-geometrical model theory , it is able to determine the termination point, when the striking distance is known. The striking distance, r in m, is:

$$r = A.i^{b}............................(fromeq.(4))$$

where A and b are constants. The striking distance is depending on the peak current amplitude of the leader stroke it is also considered that with respect to leader stroke current a protective plane appears above ground whose distance from ground os given by (Kg.R) where Kg is constant given by IEEE working group between (0.5 to 1) varies according to transmission line model.‘

(note : this derivation will also be work for negative shielding angle) as we got the positions of the striking Points (Say P1 and P2) so we get the area of striking to transmission line)

fig clearly explains the striking position of leader to variously Now following points can be considered with respect to diagram
(1) The lightening strokes emmerges before point P1 will goes to ground wire i.e. the transmission line has been saved
(2) If lightening strokes goes between points P1 and P2 then it will imerges directly to the phase conductor i.e. it will cause damage to the transmission line and can harm to useful equipments.
(3) If lightening stroke immerges after point P2 then it will goes to ground and transmission line will be saved.
From above conclusions point to be considered ti is very important to reduce the area of gap between point P1 and P2

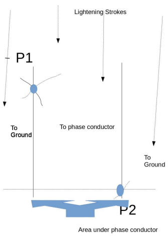


Figure 5.2: Area of region showing immerging llightening stroke

Chapter 6

Examples of analysis with pracrical Transmission line analytical structure .

6.1 Derivation for estimating the co-ordinates of points P1 and P2

Figures below shows the typical structure of the (220kV or 400kv transmission tower and 765kV transmission tower)

consider the analytical model structure of 220kV transmission tower as shown in fig 6.1 in this paper. here various physical parameters are as follows:
Hg = Height of ground wire from earth
Hp = Height of phase conductor from earth

$$\Delta = Hg - Hp$$

R = radius of protective arc produced by both conductor during lightening

$$\Theta$$

= Shielding angle between Ground wire and phase conductor now considering fig 7
appplying geometrical method for calculating co-ordinates
in traiangle ABC

$$AB = Hg - HpAnd\Theta$$

is shielding angle

$$henceBC = \Delta tan(\Theta)$$

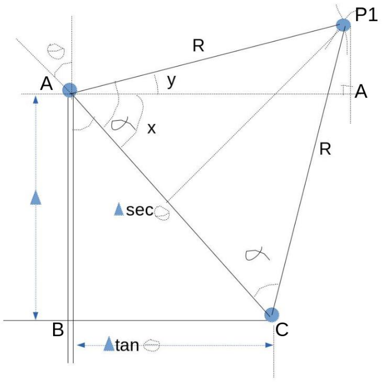


Figure 6.1: Fig for calculating co-ordinate of P1

and by pythagoras theorem

$$AC = \sqrt{\Delta^2 + (\Delta^2 tan^2(\Theta))} = \Delta sec(\Theta)$$

now co-ordinates of ground wire and phace conductor are

$$A(0, Hg)$$

and

$$C(\Delta tan(\Theta), Hp)$$

now triangle ACP1 is isoscelus triangle now

$$\alpha = \angle y + \measuredangle X$$

$$cos(\alpha) = \frac{(\Delta/2 * sec(\Theta))}{R}$$

$$therefore...\alpha = cos^{-1}(\frac{(\Delta/2 * sec(\Theta))}{R})$$

$$\alpha = y + x$$

$$\alpha = 90 - (\Theta - y)$$

$$\alpha = cos^{-1}(\frac{(\Delta/2 * sec(\Theta))}{R}) = (90 - (\Theta - y))$$

$$(\frac{(\Delta/2 * sec(\Theta))}{R}) = cos(90 - (\Theta - y))$$
$$(\frac{(\Delta/2 * sec(\Theta))}{R}) = sin(\Theta - y))$$
$$sin^{-1}(\frac{(\Delta/2 * sec(\Theta))}{R}) = (\Theta - y))$$
$$y = (\Theta - sin^{-1}(\frac{(\Delta/2 * sec(\Theta))}{R}))$$

hence co-ordinates of the point P1 will be

$$P1(Rcos(\theta), Hp + Rsin(\Theta))$$

And for finding co-ordinates of piont P2 we can use generalized circle equation

$$(x - x1)^2 + (y - y1)^2 = R^2$$

$$y = KgR$$

$$y1 = Hp$$

$$x1 = (\Delta tan(\Theta))$$

solving the equation we get co-ordinate of P2

$$P2(\sqrt{R^2 - (KgR - Hp)}) + (\Delta tan(\Theta), KgR)$$

In this way we get X distance of both co-ordinate so be can find rhe x distance (P2-P1) where lightening strokes can be immerges
if we are calculating the the area for 100km Transmission line we can simply use following formula

$$a = \frac{(P2 - P1) * 100}{1000}$$

Probability of the distribution of lightening ober the given current range can be find by standard formula The cumulative Probability of If exceeding I is given by

$$P(I_f > I) = \frac{1}{1 + (\frac{I}{I_{first}})^{2.6}}$$

where 10kA¡I¡100kA

$$I_{first}$$

is 31kA
And I is in kA If we calculate all values for stroke current ranging from 10kA to

100kA we get all values and if we multily column of Area and probability function and add all column value we get Number of strokes immerges in phase conductor and ground wire in 100km per year.

Similarly we can calculate all the values of lightening strokes for groung wire

.

- fig 8 220 or 400kV transmission line

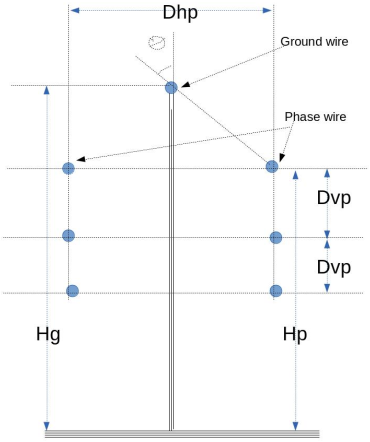


Figure 6.2: fig 220 or 400kV transmission line

- fig 9 765kV transmission line

6.2 Standard values for doing calculation

Generalised formula for Striking distance R is given as

$$R = aI_p^b + c$$

For IEEE standard Model values are
a=10 and b=0.65 and c=0
And for Height dependent model(Rizk Model)

$$a = 4027Hg^{0.41}$$

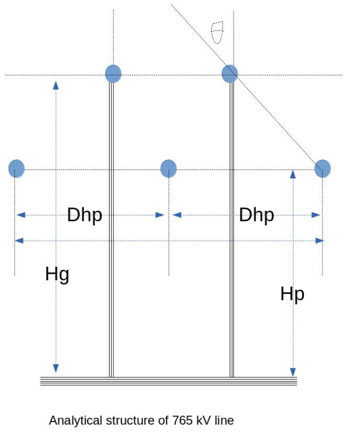


Figure 6.3: 765kV transmission line structure

and b=0.55 and c=0
For voltage dependent model all values considerd according to IEEE model. whre voltage given as

$$V = 5 * 10^6 I_p^{0.65}$$

6.3 Sample calculation for 220 kv transmission tower

consider a case of Double circuit (220kV) line having shielding angle as follows
Hp=7m
Dvp= Phase to phase vertical distance = 6.7m
Dhp= Phase to phase horizontal distance = 12.6m
shielding angle = 20 degree.

- now we consider calculations for IEEE model

(Reference fig (8))
we take peak value of leader current 20kA .
now Hp =(7+(607*2)) =20.4m

$$\Delta = 17.309$$

$$Hg = Hp + \Delta$$

Hg = 38.82

$$R = 10I_p^{0.65}$$

Ip=20kA
R=70.092
so starting point P1 will be

$$x1 = Rcos(\Theta - sin^{-1}(\frac{\Delta sec(\Theta)}{2R}))$$

x1=66.22m and ending point will be

$$x_2 = \sqrt{R^2 - (KgR - Hg)^2} + (\Delta tan\Theta)$$

x2=74.84m.
so area of lightening strokes goes to phase conductor will be

$$a_p = \frac{(x_2 - x_1) * 100}{1000}$$
$$a_p = 0.862m$$

and area of lightening strokes goes to ground wire will be

$$a_g = \frac{(x_1 - x_0 * 100}{1000}$$

here

$$x_0 = 0$$

$$a_p = 6.622m$$

Probability distribution function for considering current limit (17.5 to 22.5kA)

$$P(I_p > I_1) - P(I_p > I_2)$$

$$\frac{1}{1 + \frac{I_1}{I_f}} - \frac{1}{1 + \frac{I_2}{I_f}}$$

here If=31kA
Therefore P=0.118
So effective area of lightening on phase conductor will be

$$a_f = P * a_f$$

$$a_f = 0.0342m^2$$

So effective area of lightening on ground wire will be

$$a_{fg} = P * a_g$$

$$a_f = 0.7814m^2$$

if further we calculate for each current ranging from 10 to 100kA and add last column we get a numerical value in termn of number of lightening strokes immerges for 100m line per year

- now we consider calculations for Height dependent(Rizk model) model

we take peak value of leader current 20kA .
now Hp =(7+(607*2)) =20.4m

$$\Delta = 17.309$$

$$Hg = Hp + \Delta$$

Hg = 38.82

$$R = aI_p^b$$

Ip=20kA

$$a = 4.27Hg^{0.41}$$

a=19.14
b=0.55
so striking distance will be as

$$R = 19.14I_p^{0.55}$$

R=99.42
so starting point P1 will be

$$x1 = Rcos(\Theta - sin^{-1}(\frac{\Delta sec(\Theta)}{2R}))$$

x1=96.17 and ending point will be

$$x_2 = \sqrt{R^2 - (KgR - Hg)^2} + (\Delta tan\Theta)$$

x2=101.301
so area of lightening strokes goes to phase conductor will be

$$a_p = \frac{(x_2 - x_1) * 100}{1000}$$

$$a_p = 0.493$$

and area of lightening strokes goes to ground wire will be

$$a_g = \frac{(x_1 - x_0 * 100}{1000}$$

here

$$x_0 = 0$$

$$a_g = 9.617m$$

Probability distribution function for considering current limit (17.5 to 22.5kA)

$$P(I_p > I_1) - P(I_p > I_2)$$

$$\frac{1}{1 + \frac{I_1}{I_f}} - \frac{1}{1 + \frac{I_2}{I_f}}$$

here If=31kA
Therefore P=0.118
So effective area of lightening on phase conductor will be

$$a_f = P * a_f$$

$$a_f = 0.0582m^2$$

So effective area of lightening on ground wire will be

$$a_{fg} = P * a_g$$

$$a_f = 1.1348m^2$$

if further we calculate for each current ranging from 10 to 100kA and add last column we get a numerical value in termn of number of lightening strokes immerges for 100m line per year while doing calculations for height Dependent Model it is clear that very less number of strokes goes to phase conductor and maximum number of lightening goes to ground wire this results that 220kV double circuit line is much safer(i.e.) protected with height dependent model.

we can do further calculations with different shielding angle and with different lightening structurs for evaluating best possible values of shielding angle of different transmission line structure .

6.3.1 Further calculations for 765kV line with structure parameter as

with considering reference figure (9) we have
Dhp=phase to phase conductor didtance = 9m
Hp= height of phase conductor above ground=12m
Hg= height of ground wire above ground =17.55m
Dg= gound conductor to conductor space= 12.82m

- considering calculations for Height dependent(Rizk model) model

we take peak value of leader current ranging from 10 to 100kA
now Hp = 12m

$$\Delta = 8.55$$

$$Hg = Hp + \Delta$$

Hg = 17.55m

$$R = aI_p^b$$

$$a = 4.27Hg^{0.41}$$

a=13.82
b=0.55
so striking distance will be as

$$R = 13.82I_p^{0.55}$$

so starting point P1 will be

$$x1 = Rcos(\Theta - sin^{-1}(\frac{\Delta sec(\Theta)}{2R}))$$

and ending point will be

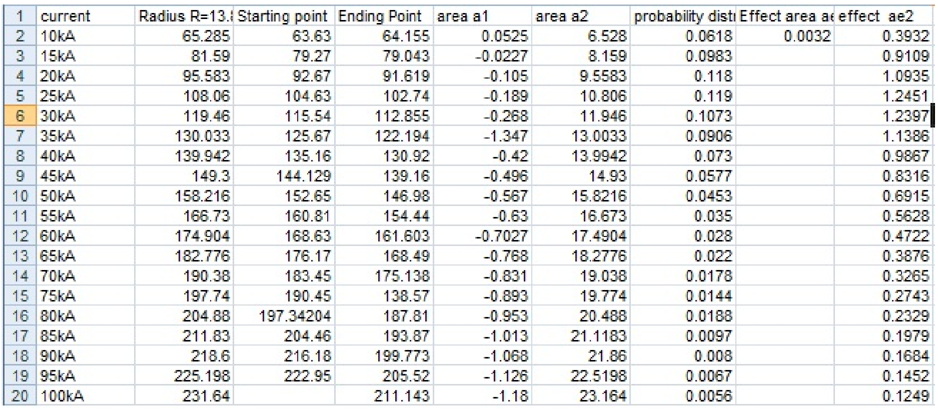
$$x_2 = \sqrt{R^2 - (KgR - Hg)^2} + (\Delta tan\Theta)$$

so area of lightening strokes goes to phase conductor will be

$$a_p = \frac{(x_2 - x_1) * 100}{1000}$$

and area of lightening strokes goes to ground wire will be

$$a_g = \frac{(x_1 - x_0 * 100}{1000}$$



1	current	Radius R=13.	Starting point	Ending Point	area a1	area a2	probability dist	Effect area a	effect ae2
2	10kA	65.285	63.63	64.155	0.0525	6.528	0.0618	0.0032	0.3932
3	15kA	81.59	79.27	79.043	-0.0227	8.159	0.0983		0.9109
4	20kA	95.583	92.67	91.619	-0.105	9.5583	0.118		1.0935
5	25kA	108.06	104.63	102.74	-0.189	10.806	0.119		1.2451
6	30kA	119.46	115.54	112.855	-0.268	11.946	0.1073		1.2397
7	35kA	130.033	125.67	122.194	-1.347	13.0033	0.0906		1.1386
8	40kA	139.942	135.16	130.92	-0.42	13.9942	0.073		0.9867
9	45kA	149.3	144.129	139.16	-0.496	14.93	0.0577		0.8316
10	50kA	158.216	152.65	146.98	-0.567	15.8216	0.0453		0.6915
11	55kA	166.73	160.81	154.44	-0.63	16.673	0.035		0.5628
12	60kA	174.904	168.63	161.603	-0.7027	17.4904	0.028		0.4722
13	65kA	182.776	176.17	168.49	-0.768	18.2776	0.022		0.3876
14	70kA	190.38	183.45	175.138	-0.831	19.038	0.0178		0.3265
15	75kA	197.74	190.45	138.57	-0.893	19.774	0.0144		0.2743
16	80kA	204.88	197.34204	187.81	-0.953	20.488	0.0188		0.2329
17	85kA	211.83	204.46	193.87	-1.013	21.1183	0.0097		0.1979
18	90kA	218.6	216.18	199.773	-1.068	21.86	0.008		0.1684
19	95kA	225.198	222.95	205.52	-1.126	22.5198	0.0067		0.1452
20	100kA	231.64		211.143	-1.18	23.164	0.0056		0.1249

Figure 6.4: calculation table of old striking distance

here

$$x_0 = 0$$

Probability distribution function for considering current limit (

$$I_1 to I_2$$

)

$$P(I_p > I_1) - P(I_p > I_2)$$

$$\frac{1}{1+\frac{I_1}{I_f}} - \frac{1}{1+\frac{I_2}{I_f}}$$

here If=31kA
here Kg=0.5
So effective area of lightening on phase conductor will be

$$a_f = P * a_f$$

So effective area of lightening on ground wire will be

$$a_{fg} = P * a_g$$

calculation Table for current ranging from 10 to 100kA

effective area of phase conductor is negative going hence it proved that this height dependent model is effective for protection against shielding failure.

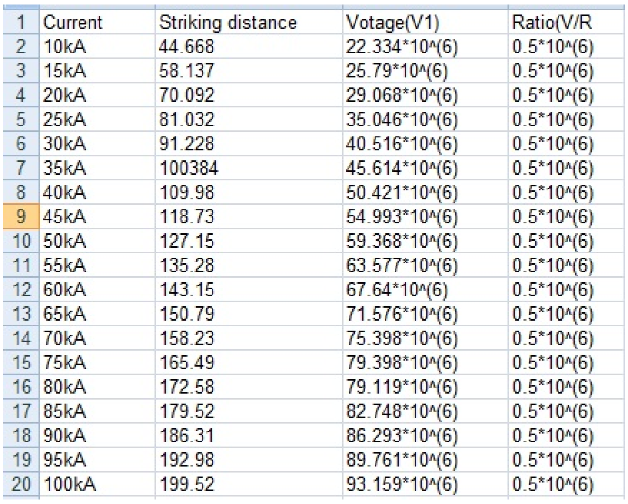
6.3.2 Calculations for voltage dependent model (considering IEEE standard values)

$$R = aI_p^b$$

here a=10 and b=0.55

$$V = 5 * 10^6 I_p^{0.65}$$

then we calculate v/R column this ratio will only applicable for ground wire (Because ground wire is at zero potential) but for phase conductor its V/R ratio will be different(Because of its own high potential) hence there will be change in striking distance because of this phenomenon



1	Current	Striking distance	Votage(V1)	Ratio(V/R
2	10kA	44.668	22.334*10^(6)	0.5*10^(6)
3	15kA	58.137	25.79*10^(6)	0.5*10^(6)
4	20kA	70.092	29.068*10^(6)	0.5*10^(6)
5	25kA	81.032	35.046*10^(6)	0.5*10^(6)
6	30kA	91.228	40.516*10^(6)	0.5*10^(6)
7	35kA	100384	45.614*10^(6)	0.5*10^(6)
8	40kA	109.98	50.421*10^(6)	0.5*10^(6)
9	45kA	118.73	54.993*10^(6)	0.5*10^(6)
10	50kA	127.15	59.368*10^(6)	0.5*10^(6)
11	55kA	135.28	63.577*10^(6)	0.5*10^(6)
12	60kA	143.15	67.64*10^(6)	0.5*10^(6)
13	65kA	150.79	71.576*10^(6)	0.5*10^(6)
14	70kA	158.23	75.398*10^(6)	0.5*10^(6)
15	75kA	165.49	79.398*10^(6)	0.5*10^(6)
16	80kA	172.58	79.119*10^(6)	0.5*10^(6)
17	85kA	179.52	82.748*10^(6)	0.5*10^(6)
18	90kA	186.31	86.293*10^(6)	0.5*10^(6)
19	95kA	192.98	89.761*10^(6)	0.5*10^(6)
20	100kA	199.52	93.159*10^(6)	0.5*10^(6)

Figure 6.5: calculation table for new striking distance

from this table table it is concluded that there will be constant striking distance for ground wire and there will be constant retio of voltage and striking distance (v/R) (i.e. 500kV/m)

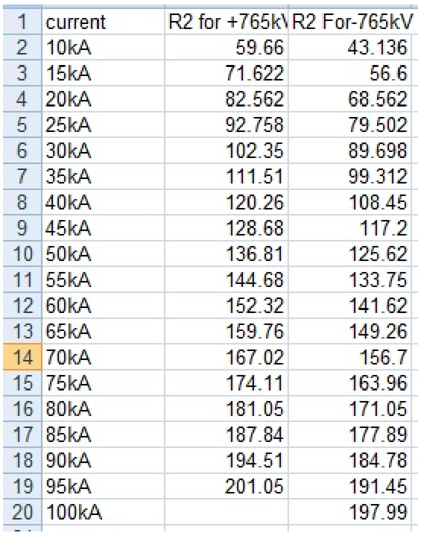
There will be different striking distance for phase conductor for both positive and negative magnitude of the 765kV line
so new striking distance will be given as

$$R_2 = Vg * \frac{(5 * 10^6 Ip^{0.65} \pm (\sqrt{\frac{2}{3}}))}{500 * 10^3}$$

for all values of current ranging from 10kA to 100kA. for Further example consider following table

from the calculation table one thing could be noted that there will be very small difference for new striking distance so new co-ordinates can be calculated by following circle equations

$$(x - 0)^2) + (y - Hg)^2 = R^2$$



current	R2 for +765k	R2 For-765kV
10kA	59.66	43.136
15kA	71.622	56.6
20kA	82.562	68.562
25kA	92.758	79.502
30kA	102.35	89.698
35kA	111.51	99.312
40kA	120.26	108.45
45kA	128.68	117.2
50kA	136.81	125.62
55kA	144.68	133.75
60kA	152.32	141.62
65kA	159.76	149.26
70kA	167.02	156.7
75kA	174.11	163.96
80kA	181.05	171.05
85kA	187.84	177.89
90kA	194.51	184.78
95kA	201.05	191.45
100kA		197.99

Figure 6.6: calculation table for new striking distance

$$(x - \Delta tan(\Theta))^2) + (y - Hp)^2 = R_1^2$$

but numeracally there will be very less difference between new striking distance and old striking distance so variation because of self potential of 765kV line can be neglected

Chapter 7

Conclusion

In this report i have done many analysis for various model of over head transmission lines (viz. IEEE model, Height dependent model, height independent model, rizk Model) for constant heights, different heights along with different different shielding angle that would give better approximation values which will be best suited for construction of certain typical overhead transmission line structure . further calculation gives best necessary data for construction of the line and because of construction work certain kind of transmission line can be protected against lightening strokes(leader) at certain high level and will be beneficilal for saving nations economy (Because higher loss in economy due to lightening be further will be decreased to desired level).

The study was achieved on double circuit real line 220kV/400kv and 765 kV line. The results indicated in this work show that the lightning current (amplitude, front time) and the tower shielding angle must be taken into account in lightning protection studies. The major part of the surge current was dissipated through the ground. Moreover the improvement of the transmission lines performances does not ensure alone a complete protection and secondary protections are then essential.

The more our life depends on electric power, communication, and electronic systems, the more frequent threat of lightning hazards will become. Accordingly, frequent threat of lightning hazards will become.consequence would be. The conventional passive lightning protection methods couldnt completely fit for the demand at present. Its necessary to research and apply the Active Lightning Protection technologies to important industries and critical fields.

Chapter 8

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